Dark Energy and the AWE* hypothesis

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* AWE means also Abnormally Weighting Energy
One of the most Challenging problems in Physics

- Several cosmological observations demonstrated that the expansion of the universe is accelerating

- What is causing this acceleration?

- How can we learn more about this acceleration, the Dark Energy it implies, and the questions it raises?

- The Dark Energy asks the fundamental principles of our cosmological paradigm
Outline

- Fundamental Principles in Cosmology.
- Observational Evidences of Dark Energy.
- Nature of Dark Energy.
  - Theoretical Interpretations:
    - DE as a new exotic energy component or as a violation of a (Strong) Cosmological Principle or as an extension of GR.
    - An « Iceberg » of Physical Theories behind the Dark Energy
- The AWE hypothesis.
- Toward an unification of DM and DE problems.
  - A natural « dual GR » at cosmological scales
  - Why the concordance model appears correct?
  - A natural phantom dark energy
  - AWE dark matter as a time-dependent inertial mass
  - Remarkable observational predictions
- Gravitation - Microphysics
The Principle of General Covariance: Generalization from Galileo to Einstein

The Equivalence Principle: Universality of the free-fall ($M_{\text{inertial}} = M_{\text{gravitational}}$) \(^{(10^{-12})}\).

Einstein's General Relativity does not distinguish these two principles

- WEP: weak equivalence principle: Test bodies fall with the same acceleration independently of internal structure or composition
- SEP: Strong equivalence principle: Test bodies fall with the same acceleration independently of gravitational binding energy.

\[
R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}
\]

Einstein's General Relativity is the standard model of gravitation

Usually, the Cosmological Principle: Homogeneous and isotropic Universe

- From theoretical point of view, it means the dynamics of the Universe is given only by $a(t)$

  \[ds^2 = dt^2 - a(t)^2 \left[\frac{dr^2}{1 - kr^2} + r^2 d\theta^2 + r^2 \sin^2 \theta \, d\phi^2\right]\]
Observational Evidences of Dark Energy

Supernovae type Ia

- Standard candles
- Their intrinsic luminosity is known, their apparent luminosity can be precisely measured (P.S. Corasaniti 2006)
- The ratio of the two can provide the luminosity-distance ($d_L$) of the supernova, the red shift $z$ can be measured independently from spectroscopy
- Finally, one can obtain $d_L(z)$ or equivalently the magnitude($z$) and draw a Hubble diagram

Type Ia Supernovae appear fainter than expected:
Cosmic expansion has recently accelerated or (and?) Supernovae are not standard candles at that time

![Graph showing the relationship between distance modulus and redshift.](image)
Observational Evidences of Dark Energy

Evidence from Cosmic Microwave Background Radiation (CMB)

- CMB is an almost isotropic relic radiation of $T=2.725\pm0.002$ K
- CMB is a strong pillar of the Big Bang cosmology
- It is a powerful tool to use in order to constrain several cosmological parameters

Geometry: Flat Universe ($\Omega_\mathrm{T}\sim1$), Present Energy Content: Matter: $\sim24\%$ with Baryons: $\sim4\%$

=> Dark Matter: $\sim20\%$, => Missing Dark Energy: $\sim76\%$!
Observational Evidences of Dark Energy

Numerous observational evidences: BAO, LSS, WL …

- Baryonic Acoustic Oscillations

![Graph showing 2-point correlation function vs. Distance r (h^{-1} Mpc)]

- Large-Scale distribution of galaxies (Power Spectrum)
  2dFGRS: 0.65 < \Omega_\Lambda < 0.85 (95% C.L.), SDSS: \Omega_M = 0.24 \pm 0.02 (95% C.L.)

- Counting clusters of galaxies can infer the matter energy density in the universe, \Omega_M \sim 0.3
Observational Evidences of Dark Energy

Cosmic complementarity

The Concordance Model $\Lambda$CDM

Baryons $\sim 5\%$

CDM $\sim 25\%$

Radiations $\sim 0.01\%$

Dark Energy $\sim 70\%$

Dark Matter ?  Dark Energy ?
Nature of Dark Energy?

Cosmological Paradigm
- Covariance Principle
- Equivalence Principle
- Comological Principle

\[
\begin{align*}
\left( \frac{\dot{a}}{a} \right)^2 + \frac{k}{a^2} &= \frac{8\pi G \rho}{3} \\
\frac{\ddot{a}}{a} &= -\frac{4\pi G}{3} (\rho + 3P)
\end{align*}
\]

New energy-component (\(\rho\))
- Extensions to GR!!

The Hypothesis
- "Einstein’s General Relativity is the standard model of gravitation" is conserved

Standard Model
- and theoretical extensions

Extensions to GR can be interpreted as an extra energy-component in a « quasi » Friedmann model?

All proposed models of dark energy can be interpreted as an extra energy-component in a “quasi” Friedmann model

*Reinterpreting dark energy through backreaction: the minimally coupled morphon field,

The simple cosmological constant can be seen as the top of the iceberg of a deeper intriguing theory of gravitation:

$$S_{\text{Einstein}} = \frac{1}{2\kappa} \int d^4x \sqrt{-g} \{R + \Lambda\}$$

In the framework of Quintessence, \(\Lambda\) corresponds to the limiting case where the scalar field freezes in a non-vanishing energy state:

$$S_{\text{grav}} = \frac{1}{2\kappa} \int d^4x \sqrt{-g} \{R - 2\partial_\mu \phi \partial^\mu \phi + V(\phi)\}$$  \quad \text{(SEP+WEP)}

Quintessence itself can be seen as the limiting case of Tensor-scalar gravity with negligible violation of Strong Equivalence Principle (SEP):

$$S = S_{\text{grav}}[g_{\mu\nu}, \phi] + S_{\text{matter}}[\psi^i, A^{\phi}_{\text{matter}}(\phi)g_{\mu\nu}]$$  \quad \text{(NO SEP, WEP)}

Finally, there is a generalization of the non-minimal couplings that embed the previous TST: the case where the non-minimal couplings are not universal:

$$S = S_{\text{grav}}[g_{\mu\nu}, \phi] + \sum_{\text{matter } i} S_i[\psi^i, A^2(\phi)g_{\mu\nu}]$$  \quad \text{(NO SEP, NO WEP)}

This will constitutes the starting point of the Abnormally Weighting Energy (AWE) Hypothesis.
The AWE Hypothesis: Cosmology without Equivalence Principle

Tensor-scalar theories of gravitation* (universal coupling => NO SEP, WEP)

- Dicke-Jordan Frame (Observational Frame)

\[
S = \frac{1}{2} \int d^4 x \sqrt{-\tilde{g}} \left\{ \Phi R - \frac{\omega(\Phi)}{\Phi} \tilde{g}^{\mu\nu} \partial_\mu \Phi \partial_\nu \Phi \right\} + S_M [\Psi_M, \tilde{g}_{\mu\nu}]
\]

- Einstein Frame \( \tilde{g}_{\mu\nu} = A_M^2(\varphi) g_{\mu\nu}^* \)

\[
S = \frac{1}{2\kappa} \int d^4 x \sqrt{-g^*} \left\{ R - 2 \partial_\mu \varphi \partial^\mu \varphi \right\} + S_M \left[ \Psi_M, A_M^2(\varphi) g_{\mu\nu}^* \right]
\]

- Cosmological dynamics

\[
\left( \frac{2}{3 - \varphi'^2} \right) \varphi'' + \left( 1 - \frac{P/\rho}{\rho} \right) \varphi' + \left( 1 - 3 \frac{P/\rho}{\rho} \right) \alpha_M(\varphi) = 0
\]

\[ V(\varphi) = \int \alpha(\varphi) d\varphi \]

GR

Post-Newtonian Constraints

\[
|\gamma - 1| = 2 \frac{\alpha_0^2}{(1 + \alpha_0^2)} < 2 \times 10^{-5}
\]

\[
|\beta - 1| = \left| \frac{d\alpha}{d\varphi} \right| \frac{\alpha_0^2}{2(1 + \alpha_0^2)} < 6 \times 10^{-4}
\]

\[
\left| \frac{\dot{G}}{G} \right| < 6 \times 10^{-12} \text{ yr}^{-1}
\]

*Jordan 1949, Fierz 1956, Brans & Dicke 1961
The AWE Hypothesis: The equivalence principle

- The Equivalence Principle: all kinds of energies couple in the same way to gravitation
  - Weak equivalence principle (WEP): non-gravitational energies
  - Strong equivalence principle (SEP): gravitational binding energy

- Effective theories of gravitation:
  - Tensor Scalar gravity, low-energy limit of string theory *

\[ S_{\text{grav}} = \frac{1}{2\kappa} \int d^4 x \sqrt{-g} \{ R - 2 \partial_\mu \varphi \partial^\mu \varphi \} \]
\[ S_{\text{matter}} = S_{\text{gauge}} \left[ \psi_{\text{gauge}}, A_{\text{gauge}}^2 (\varphi) g_{\mu\nu} \right] + S_{\text{fermions}} \left[ \psi_{\text{fermions}}, A_{\text{fermions}}^2 (\varphi) g_{\mu\nu} \right] + \ldots \]

\( \Psi_i \): matter field, \( A_i(\varphi) \) coupling functions, \( \varphi \) « dilaton »,

Effective metric felt by energy \( i \) (« observable » frame for \( i \))

\[ \tilde{g}_{\mu\nu} = A_i^2 (\varphi) g_{\mu\nu} \]

**Gravitation: spin 2 (g_{\mu\nu})+ spin 0 (\varphi) : NO SEP !**

**Non-universal coupling (A_{gauge}(\varphi) \neq A_{fermions}(\varphi), etc.) : NO WEP \Rightarrow NO SEP !**

* Gasperini 2007, Damour & Polyakov 1994
The AWE Hypothesis

(In Einstein Frame) Energy content of the Universe is divided in 3 parts

- A gravitational sector described by pure spin 2 (graviton) and spin 0 (dilaton) degrees of freedom and a matter sector containing: The ordinary matter (baryons, photons, ...), ruled by the equivalence principle, defines the observable frame

\[
S = \frac{1}{2\kappa} \int d^4 x \sqrt{-g} \left\{ R - 2 \partial_\mu \varphi \partial^\mu \varphi \right\} + S_M \left[ \psi_M , A_M^2(\varphi) g^*{}_{\mu\nu} \right] + S_{AWE} \left[ \psi_{AWE} , A_{AWE}^2(\varphi) g^*{}_{\mu\nu} \right]
\]

- AWE sector violating the weak equivalence principle

\[
A_M(\varphi) \neq A_{AWE}(\varphi)
\]

(In Dicke-Jordan Observable Frame) mixed degrees-of-freedom

- The ordinary matter (baryons, photons, ...), ruled by the equivalence principle, defines the observable frame and follow geodesics of metric not of pure spin-2

- Invisible (AWE) sector has varying mass

\[
S = \frac{1}{2} \int d^4 \tilde{x} \sqrt{-\tilde{g}} \left\{ \Phi \tilde{R} - \frac{\omega(\Phi)}{\Phi} \tilde{g}^{\mu\nu} \partial_\mu \Phi \partial_\nu \Phi \right\} + S_M \left[ \psi_M , \tilde{g}_{\mu\nu} \right] + S_{AWE} \left[ \psi_{AWE} , M^2(\varphi) \tilde{g}_{\mu\nu} \right]
\]

\[
\tilde{g}_{\mu\nu} = A_M^2(\varphi) g_{\mu\nu} \quad \tilde{a}(\tilde{t}) = A_m(\varphi) a(t) \quad \tilde{H}(\tilde{t}) = \frac{1}{\tilde{a}} \frac{d\tilde{a}}{d\tilde{t}} \quad \tilde{q}(\tilde{t}) = \frac{\tilde{a} \tilde{a}}{\tilde{a}^2}
\]
The AWE Hypothesis: cosmological models

**Einstein Frame**

\[
S = \frac{1}{2\kappa} \int d^4x \sqrt{-g} \left\{ R - 2\partial_\mu \varphi \partial^\mu \varphi \right\} + S_M \left[ \psi_M, A_M^2(\varphi) g^{\mu\nu} \right] + S_{AWE} \left[ \psi_{AWE}, A_{AWE}^2(\varphi) g^{\mu\nu} \right]
\]

The Action of the AWE Hypothesis generalizes the models DM-DE couplings Das, Corasaniti, Khoury 2006: \( A_{AWE}(\varphi) = A_{DM}(\varphi) = e^{\beta \varphi}, A_{M}(\varphi) = 1 \)

However the AWE Hypothesis consider the scalar field is massless

**FLRW**

\[
H_*^2 = \left( \frac{\dot{a}_*}{a_*} \right)^2 = \frac{\dot{\varphi}^2}{3} + 8\pi G_* \left( \rho_\ast_{M} + \rho_{\ast,AWE} \right), \quad \frac{\ddot{a}_*}{a_*} = -\frac{2}{3} \dot{\varphi}^2 - \frac{8\pi G_*}{6} \left( \rho_\ast_{M} + 3 p_\ast_{M} + \rho_{\ast,AWE} + 3 p_{\ast,AWE} \right)
\]

\[
\ddot{\varphi} + 3 \frac{\dot{a}_*}{a_*} \dot{\varphi} + 4\pi G_* \alpha_M(\varphi) \left( \rho_\ast_{M} - 3 p_\ast_{M} \right) + 4\pi G_* \alpha_{AWE}(\varphi) \left( \rho_{\ast,AWE} - 3 p_{\ast,AWE} \right) = 0
\]

Let us consider that the AWE sector is a pressureless fluid and focus on the matter-dominated era of the universe

**Conservation equations**

\[
\nabla \dot{\rho}_{\ast,M,AWE}^* + 3 \frac{\dot{a}_*}{a_*} \rho_{\ast,M,AWE}^* = \alpha_{M,AWE}(\varphi) \dot{\varphi} \rho_{\ast,M,AWE}^*
\]

\[
\rho_{\ast,M,AWE}^* = A_{M,AWE}(\varphi) \frac{C_{M,AWE}}{a_*^3}
\]

\[
\rho_{BI} \propto a^{-3}
\]
Dark Energy as a relaxation of the Weak Equivalence Principle on Cosmological Scales.

The previous two fluids system can be rewritten as one field system

$$\rho_{T}^{*} = \rho_{M}^{*} + \rho_{AWE}^{*} = \frac{A(\varphi)C_{M}}{a^{*3}} , A(\varphi) = A_{M}(\varphi) + A_{AWE}(\varphi)$$

We deduce

$$\frac{2}{3-\varphi'^{2}} \varphi'' + \varphi' + \mathcal{N}(\varphi) = 0 \quad \mathcal{N}(\varphi) = \frac{d \left( \log \left( A(\varphi) \right) \right) }{d \varphi} = \alpha_{M}(\varphi) + \frac{\alpha_{AWE}(\varphi) - \alpha_{M}(\varphi)}{1 + \frac{\rho_{M}^{*}(\varphi)}{\rho_{AWE}^{*}(\varphi)}} \equiv \frac{d}{d \log a^{*}}$$

- TST in matter-dominated era are easily retrieved if $$\alpha_{M}(\varphi) = \alpha_{AWE}(\varphi) = \mathcal{N}(\varphi)$$, which corresponds to no violation of the WEP and/or if $$\rho_{M}^{*} \gg \rho_{AWE}^{*}$$.
- The present TST exhibits a sophisticated convergence mechanism even in the case of very simple constitutive coupling functions

$$R_{i} \frac{A_{M}(\varphi)}{A_{AWE}(\varphi)} = \frac{\rho_{M}(\varphi)}{\rho_{AWE}(\varphi)}$$

$$\mathcal{N}(\varphi_{\infty}) = 0 \quad \alpha_{M}(\varphi_{\infty}) R_{i} \frac{A_{M}(\varphi_{\infty})}{A_{AWE}(\varphi_{\infty})} + \alpha_{AWE}(\varphi_{\infty}) = 0$$
Dark Energy as a relaxation of the Weak Equivalence Principle on Cosmological Scales.

**Chameleon-like Effect** (Khoury & Weltman 2004; Mota & Shaw 2006; Brax et al. 2004; Mota & Barrow 2004).

- Relaxation of Weak Equivalence Principle on cosmological scales: $\rho_b / \rho_{DM} << 1$
- Restricted WEP on visible matter (« normally weighting » sector): $\rho_b / \rho_{DM} >> 1$
- One space-time but two couplings $G_M$ and $G_{AWE}$ (« minimal » WEP violation) corresponding to different minima in the couplings functions
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- For any set of constitutive couplings functions, $A_M(\phi), A_{AWE}(\phi)$, the resulting coupling function $A$ has at least one extremum and there exists a finite value of the effective gravitational coupling constant $\tilde{G}_c(\phi)$ which is different from GR.

\[
\alpha_M(\phi) = k_M \phi, \quad \alpha_{AWE}(\phi) = k_{AWE} \phi
\]

\[
A(\phi) = e^{\frac{k_A \phi^2}{2}} + \frac{C_{AWE}}{C_M} e^{\frac{k_M \phi^2}{2}}, \text{ avec } k_A k_M < 0
\]

\[
\nabla(\phi) = \frac{d \log(A(\phi))}{d\phi}
\]

- The attracting value $\phi_\infty$ depends on the ratio of usual matter over abnormally weighting dust and is intermediate between the value of $\phi$ for which $A_M(\phi)$ extremum (when $\rho_{M}^* >> \rho_{AWE}^*$) and the value of $\phi$ for which $A_{AWE}(\phi)$ is extremum (when $\rho_{M}^* << \rho_{AWE}^*$).
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Astrophysical discussion

- The violation of the WEP strongly depends on the ratio of usual matter energy density over AWE.
  - As both usual matter and AWE clusters, this violation is different with the scale considered.
  - Furthermore, the AWE is assumed to be dark and its gravitational collapse will be therefore quite different due to the absence of the dissipative processes that allows usual matter like baryons to cluster so much compared to DM at low scales.

- The domination of usual matter over AWE DM at small scales, which is a consequence of the different physical processes to which baryons are submitted will tend to make the WEP well verified at small scales.
  - The usual convergence mechanism toward GR with $G_*$ (Grav. Cst bare value) as an asymptotic value of the gravitational coupling constant is acting on scales where AWE DM is sub-dominant, i.e. at low scales.
  - We therefore conjecture that GR is verified on the very small (sub-galactic) scales at which the solar system or binary pulsar system constraints on GR have been established.

- We then interprete the Hubble diagram of far-away supernovae only in terms of cosmic acceleration without corrections due to the variation of the gravitational constant for compact, gravitationally bound objects.
- The precise computation of the deviations from GR with the scale would require a complexe study of the structure formation in this AWE model.
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- **Observational Frame**

\[ \tilde{g}_{\mu \nu} = A_M^2(\varphi)g_{\mu \nu}^*, \tilde{G}_c = A_M^2(\varphi)G^* \]

\[ \tilde{T}^\mu_{\nu}^M = A_M^{-4}(\varphi)T^\mu_{\nu}^M, \tilde{T}^\mu_{\nu}^{AWE} = A_M^{-4}(\varphi)T^\mu_{\nu}^{AWE} \]

- **A (quasi) Friedman description**

\[ \tilde{H} = \frac{\dot{a}}{a} = A_M^{-1}(\varphi)H^*(1 + \alpha_M(\varphi)\varphi') \]

\[ \tilde{H}^2 = \frac{8\pi\tilde{G}_c}{3}(\tilde{\rho}_M + \tilde{\rho}_{AWE}) \times \left(1 + \frac{\varphi'^2(1 + 3\alpha_M^2) + 6\alpha_M\varphi'}{3 - \varphi'^2}\right) \]

\[ \tilde{\Omega}_{\varphi} = (\tilde{\Omega}_M + \tilde{\Omega}_{AWE})\varphi'^2 \left(1 + 3\alpha_M^2\right) + 6\alpha_M\varphi' \]

\[ \tilde{\Omega}_{M,AWE} = \frac{8\pi\tilde{G}_c\tilde{\rho}_{M,AWE}}{3\tilde{H}^2} \]

FLRW-like but DM not scaling in \(a^{-3}\) (varying mass), and Exotic DE tracking DM and baryons

- **Accelating Universe in the AWE Hypothesis**

\[ \frac{1}{\tilde{a}} \frac{d^2\tilde{a}}{dt^2} = -\frac{4\pi\tilde{G}_c}{3}(\tilde{\rho}_M + \tilde{\rho}_{AWE}) \times \left(1 - \frac{2\varphi'}{3 - \varphi'^2} \left(\varphi' \left(\frac{d\alpha_M}{d\varphi} - \frac{2}{3}\right) - 2\alpha_M\right)\right) \]

\[ -4\pi\tilde{G}_c\alpha_M(\alpha_M\tilde{\rho}_M + \alpha_{AWE}\tilde{\rho}_{AWE}) \]

Acceleration occurs in the observational frame, for instance, if \(\alpha_{AWE} < 0\) and \(\rho_{AWE} \gg \rho_M\)
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- Type Ia supernovae Hubble diagram (Astier et al 2006) \( \mu(z) = m - M = 5 \log_{10} d_L(z) \)
  - \( R_1 = 0.11, \quad R_\infty = 0.31, \quad \Omega_M = 0.04, \quad \Omega_{AWE} = 0.26, \quad t_0(\text{Gyr}) = 15.9, \quad \chi^2/\text{dof} = 1.03 \)

\[ \begin{align*}
\Lambda \text{CDM} & \quad \text{Blue: data from SLNS} \\
\Lambda \text{AWE} & \quad \text{Red: data from HST Gold sample}
\end{align*} \]

\( G_M(\varphi) \equiv \text{DE} \)
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: Toward an unification to DM and DE

- Type Ia supernovae Hubble diagram (HST + SNLS data)

\[
\begin{align*}
\Omega_{\text{DM}} & = 0.21^{+0.03}_{-0.01} \\
\Omega_{b} & = 0.05^{+0.06}_{-0.02}
\end{align*}
\]

- Measurement of baryons and DM distribution from SNe Ia alone!
- Independent predictions close to that of $\Lambda$CDM with a very good agreement with BBN and CMB
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: A natural phantom universe

- An accelerating Universe in the AWE hypothesis

\[
\tilde{H}^2 = \frac{8\pi G_c}{3} \left( \tilde{\rho}_T + \tilde{\rho}_{DE} \right)
\]

\[
\frac{1}{\tilde{a}} \frac{d^2 \tilde{a}}{d\tilde{t}^2} = -\frac{4\pi G_c}{3} \tilde{\rho}_T - \frac{4\pi G_c}{3} \tilde{\rho}_{DE} (1 + 3\omega_{eff})
\]

![Graph showing the evolution of \(q_{eff}\) with redshift]
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: A unified description of DM and DE

- Constraints from SNe Ia Hubble diagrams

**HST Gold DATA**

- $\Lambda$ ruled out $1\sigma$, $2\sigma$ (HST)!
- $\Omega_M$ in agreement with independant analysis!

**SNLS DATA**
Dark Energy as a relaxation of the Weak Equivalence Principle at cosmological scales: A natural phantom universe

- Constraints from SNe Ia Hubble diagrams

- A natural phantom universe (super acceleration)!
- $\Omega_B$ very good agreement with BBN and CMB analyses
The AWE Hypothesis

Reducing Dark Energy to a new property of Dark Matter:

The Anomalous Gravity

Open Question:
Test of the equivalence principle on cosmological scales?
How discriminating between all Dark Energy Models?

Implications on Structure Formation

AWE Dark Matter as a time-dependent inertial mass

\[ m^*(\varphi) \propto A_{AWE}(\varphi) \]

\[ \tilde{m}(\varphi) \propto \frac{A_{AWE}(\varphi)}{A_M(\varphi)} \]

- Structure Formation.
  - \( G_N(t) \)
  - Poisson Equation is modified
  - Inertial Mass(t)
  - Free Fall Equation is modified
  - Observational Frame
A Keystone Between Microphysics and Gravitation?

The most remarkable feature of our model is that, besides of its cosmological predictions, it allows us to deduce a new constraint relating microphysics and gravitation:

- To obtain the cosmological evolution described above, it is enough that the matter and AWE coupling functions have to be inversely proportional:

  \[ A_M(\varphi) \propto A_{AWE}(\varphi)^{-R_\infty} \]

  Where \( R_\infty = \left( \frac{\rho_b}{\rho_{DM}} \right)(t \to +\infty) \) is the ratio at which ordinary matter and DM densities freeze once the scalar field reaches the attractor \( \varphi_\infty \)

- From the cosmological data on supernovae, we find a \( R_\infty \) close to unity (at 68 % confidence level)

  \[ R_\infty = 1.26^{+0.95}_{-0.68}(HST) \quad , \quad R_\infty = 1.38^{+1.38}_{-0.86}(SNLS) \]
A Keystone Between Microphysics and Gravitation?

We deduce an intriguing relation between the constant mass of baryons $m_b$ and the changing DM $m_{DM}$ and gravitational strenght $G_c$

\[ G_c (x^\mu) \times m_b \times m_{DM} (x_\mu) = G_N \times m_b \times \overline{m}_{DM} \]

where the bar means the Earth laboratory value.

Although this relation does not fix the bare mass of DM, it rules its scaling by imposing a conservation of the product of the gravitational charges of baryons and DM. This phenomenological law, directly deduced from cosmological data and linking together gravitational scales and masses of baryons and invisible matter glimpses at the intimate nature of gravitation.

The deep meaning of this relation constitutes a crucial question for the fundamental approaches that aim to unify gravity and microphysics with explicit space-time dependancies of masses and couplings.
Dark Energy and the AWE* hypothesis

Jean-Michel Alimi, André Füzfa
Thank you for your attention...

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